"CORROSION IN THE SOIL ENVIRONMENT: NEW YORK'S EXPERIENCE"

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INTRODUCTION

Geotechnical engineering techniques currently being applied to solve foundation problems frequently involve use of steel elements installed in the soil environment. This is the case for steel H-piles and steel reinforcing strips for mechanically stabilized earth structures. Corrosion of these elements is of concern because it affects the service life of the structures they support.

The New York State Department of Transportation (NYSDOT) has gained experience over the last few years relating to corrosion of both steel piles and galvanized steel strips. That experience is the subject of this paper, which concerns only corrosion involving mechanically stabilized earth structures and steel pile foundations.

Corrosion studies related to steel shells, sheet piling, and piles date back to the 1920's. However, the work of Melvin Romanoff of the National Bureau of Standards is foremost in this field. His Circular 579, Underground Corrosion (1), was published in 1957. In 1962, he published an important article titled "Corrosion of Steel Piling in Soils" (2).

Research work related to corrosion of steel elements in the soil environment has not received much attention since Romanoff's work was published. Meanwhile, application of geotechnical engineering techniques has required large quantities of

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steel elements for solution of engineering problems. In 1992, NYSDOT installed approximately 200,000 ft. of steel piles for structure foundations. Currently in New York there are about 200 mechanically stabilized earth structures reinforced with strips or wire mesh built since 1977 that are performing as retaining walls, bridge abutments, and wingwalls. The largest is 50 ft. high and 3,000 ft. long.

In 1987, corrosion of galvanized steel strips in a mechanically stabilized earth abutment came to our attention. It supported the west abutment of a structure over Sweet Home Road near Buffalo and had been completed in 1981. Subsequent investigation revealed that the galvanized steel strips were severely corroded, ultimately requiring its removal and replacement. The cause of this severe corrosion was directly related to the aggressive cinder-backfill material.

In 1988, a mechanically stabilized earth structure was constructed beside the Long Island Railroad near Inwood Station, which has a 660V direct current third rail. Its location raised concern about potential corrosion of galvanized steel strips in the wall resulting from stray electric currents. Two independent analyses of the site conditions were conducted, with the conclusion that based on existing conditions there was no immediate problem. However, it was recommended that periodic monitoring continue to assure that railroad operations did not change conditions so as to increase the likelihood of corrosion caused by stray electric currents.

In 1989, an opportunity arose to extract six steel H-piles from two structure foundations during the Father Baker Bridge reconstruction contract near Buffalo. Field and laboratory analysis resulted in a report documenting a loss of up to 32% of the cross-section of a steel pile that had been in place for 32 years.

Since 1988, NYSDOT has taken positive steps to assure that corrosion potential is minimized. Specification requirements for mechanically stabilized earth structure backfill have been strengthened, AASHTO laboratory test procedures have been adopted, construction monitoring of backfill material is required, and design awareness now exists of potential corrosive soil conditions.

<u>SWEET HOME ROAD CROSSING</u> (3,4,5,6,7)

In September 1980, a contract was awarded to construct a ramp over Sweet Home Road from I-990 (the Lockport Expressway) to the State University Campus near Buffalo. Foundation conditions at this location were clay over bedrock. The clay foundation soils made it necessary to construct the embankment using 80 pcf lightweight material to eliminate concern over a foundation stability problem. The material was anticipated to be blast furnace slag, which was available and had been used previously on many projects in the area. Lab testing during design by the Reinforced Earth Company indicated this was a suitable backfill.

The west abutment was to be supported by steel H-piles driven to bedrock. The lightweight embankment material was contained by a mechanically stabilized earth structure built with galvanized steel strips. NYSDOT specifications for the structure had no requirements for corrosion testing, nor did the Soil Mechanics Bureau have laboratory testing equipment or procedures to evaluate electrochemical properties of the backfill material.

The contractor elected to use cinders from an industrial waste source for the lightweight material rather than the anticipated blast furnace slag. The cinders met

weight requirements for lightweight material and were approved for the structure's backfill.

During construction, the Reinforced Earth Company sampled the cinders and subsequently tested their resistivity. These samples were obtained in July 1981, but resistivity test results were not known until later in 1981 after the structure had been completed. The test results were sent to the Department with concern expressed about low resistivity. The values were outside the Company's experience at that time. They recommended the rate of corrosion be monitored. The Department decided that the project's remaining mechanically stabilized earth structures would not be constructed using cinders.

Since the structure was already in place, it was decided to monitor corrosion rate by inserting short sections of galvanized steel strip coupons in the side slopes of the completed lightweight embankment; these were placed in September 1981 and were to be extracted at intervals at 1,2,5,10 and 20 years. The first two coupons at 1- and 2-year intervals were removed and evaluated, and found to have undergone galvanization loss within expected ranges.

In this period, a Federal Highway Administration (FHWA) research project (8) was underway and had reached the stage where a prototype meter was available to measure corrosion rate. The principal investigator approached the Department asking to experiment with the meter on the galvanized steel strips at Sweet Home Road. It was arranged to uncover several strips so that electrical connections could be made to evaluate the meter. When they were exposed in 1987, it was evident that serious corrosion had occurred.

Their state of corrosion was considered serious enough to let an emergency contract to open a trench and expose more strips at greater depths to evaluate their condition. This work resulted in removal of twelve galvanized steel strips in various stages of advanced corrosion. They were delivered to the laboratory in Albany for in-depth analyses.

The Department's Engineering Research and Development Bureau contracted with D. J. Duquette of Rensselaer Polytechnic Institute, an expert in corrosion, to obtain recommendations for backfill requirements. He prepared a report titled "An Assessment of Corrosion Problems Associated With Reinforced Earth Structures" (11). He recommended electrochemical testing with allowable limits set for suitable backfill for mechanically stabilized earth structures.

Serious concern about the structure's stability caused the Soil Mechanics Bureau to recommend replacing or buttressing the existing abutment within six months. It was replaced in June 1988. When the original abutment was demolished, the galvanized steel strips were in an obviously advanced stage of corrosion, with more serious corrosion occurring with increasing depth and increasing distance from the abutment face; this correlates to the observation that backfill moisture content increased in that direction. No corrosion existed at wall connections. Some strips were totally corroded through and discontinuous, leaving only a stain to indicate they had been. Since the corrosion rates of the short sections of galvanized steel strip coupons were not indicative of actual performance, the procedure was terminated at other sites.

It was also observed that the steel H-piles were sufficiently corroded to require

removal and replacement of sections of the piles; ultimately they were jacketed with concrete for extra protection. The most serious pile corrosion had occurred where they entered the clay soil, causing a conical depression that later filled with cinder backfill. The combination of cinders and groundwater at that location apparently accelerated the corrosion.

In 1988, the mechanically stabilized earth abutment was rebuilt using galvanized steel strips and a lightweight stone backfill material (115 pcf.). Specifications included the following FHWA requirement for electrochemical testing:

> If the State tests for corrosive potential, material failing to meet all of the requirements of TABLE 554-2 will be rejected and will not be incorporated in the work.
>
> TABLE 554-2
>
> | | |
> |---|---|
> | Resistivity... | $>$ 3000 ohm-cm.* |
> | pH... | 5 to 10 |
> | Sulphates... | $<$ 500 mg/kg. |
> | Sulphides... | $<$ 300 mg/kg. |
> | Chlorides... | $<$ 100 mg/kg. |
>
> *Resistivity testing will be done in accordance with current Departmental procedures.

FATHER BAKER BRIDGE: STEEL PILES EXTRACTED (9,10)

The experience with severely corroded galvanized steel strips and steel H-piles at the Sweet Home Road Crossing heightened awareness of potential corrosion at other locations. In 1989, an opportunity arose to extract six steel bearing piles from the

foundations of the original Father Baker Bridge during its demolition. Foundation soils here were known to be miscellaneous manmade fills and organic soils, over clay over bedrock. The miscellaneous fills were primarily cinders and slags from local industrial operations. Original construction of the bridge was completed under a 1957 contract.

Contract arrangements were made to pull six of the 32-year old piles for evaluation; each was about 70 ft. long. They were extracted from two separate sites -- three piles from each site. The groundwater level was approximately that of adjacent Lake Erie. The soil profile at one site was organic soils over clay over bedrock and maximum cross-section loss was 5%. The soil profile at the second site was slag over clay over bedrock with average loss of 22%, ranging from 6% to 32%.

During extraction, excavations were necessary providing an opportunity to sample the miscellaneous manmade fill material around the piles for subsequent laboratory testing for electrochemical properties. After their extraction, they were field evaluated by soils and materials engineers who decided to cut nine 2 ft. sections and transport them to the laboratory for further evaluation.

Each section of pile was photographed and subsequently cleaned and measured. Corrosion was extremely variable, with a maximum loss of 32% of the pile cross-section. The most severe corrosion damage was near the vicinity of the groundwater level. Electrochemical laboratory tests of the manmade fill material did not produce test results correlating to the severity of corrosion observed on the piles.

A joint report was prepared by the Soil Mechanics and Materials Bureaus

documenting the field and lab work, with a copy sent to the FHWA geotechnical group in Washington, D.C. It was subsequently distributed nationwide to all bridge engineers calling attention to the possibility of corrosion of steel H-piles that support bridges.

NYSDOT geotechnical foundation designers have been sensitized to the potential for corrosion of steel H-piles. In some cases, decisions have resulted in removing and replacing miscellaneous manmade fills or change of pile foundation design.

BUFFALO SKYWAY (11)

The Buffalo Skyway is a 1.1-mile long viaduct carried on 88 piers founded on steel H-piles about 70 ft. long. Foundation soils along the viaduct's length are known to be miscellaneous manmade fill material over clay over bedrock. The fill is a mixture of cinders, slags, and building demolition refuse deposited over the years to reclaim land from Lake Erie.

The viaduct had major superstructure rehabilitation under contract during the Father Baker Bridge investigation. It was known that a substructure rehabilitation contract would be awarded in 1991. Anticipating that contract, the Soil Mechanics Bureau developed a plan to investigate selected pier foundations with cooperation from the successful contractor for excavation and other support assistance.

The investigation's goals were twofold. The primary consideration was to develop a method of predicting corrosion potential of steel H-piles in manmade fills through in-situ and laboratory testing. Important, but secondary to the main goal was

evaluation of steel H-piles supporting the piers, which had been in place for 35 years.

The investigation plan was developed over many months. Soils and materials engineers, engineering geologists, other state geotechnical personnel, academics, consultants, and corrosion experts were all consulted. The magnitude of the field and lab work was anticipated to be time-consuming and costly.

The first testing phase involved a surface electrical resistivity survey (the Modified Wenner Method) by NYSDOT Engineering Geologists. Its purpose was to identify the lowest resistivity areas in the soil profile to assist in selecting the piers for in-depth investigation. Ultimately six piers were chosen.

Beside each of the six piers, drill holes were advanced to determine the soil profile and obtain soil samples for laboratory testing of physical and electrochemical properties. The water level was encountered at approximately the bottom of the pile cap elevations. Next, the three methods selected to obtain in-situ information on electrochemical properties of the foundation soils were performed. The first was a copper-copper sulfate reference electrode (half-cell), normally used to determine corrosion potential on steel-reinforced bridge decks. This measurement required an electrical connection through the pile cap to the pile being examined. The second method involved a device known as a "PR Monitor," that had recently been delivered to the Federal Highway Administration under a research contract. It had been developed to measure corrosion rates of galvanized steel strips in mechanically stabilized earth structures through automated polarization resistance measurements. This PR Monitor was thought to have potential for evaluating steel H-piles because

of its ability to measure solution resistance between the H-piles and half-cell test points. This was to be its first use in the field. The third method was the Geonor probe used to determine soil resistivity at various depths. The results obtained would be compared to laboratory test results and the surface electrical resistivity survey.

When the field drilling and in-situ electrochemical testing investigations were completed, steel H-piles in the outer perimeter of each pier were exposed by excavation. Soil was sampled from various elevations adjacent to the exposed pile, and at those sample locations pile thickness was measured. The steel H-piles were sandblasted before the thickness measurements.

Data from the field measurements and laboratory test results were statistically analyzed and an attempt made to correlate the results to find a reliable predictive technique. Details of the investigation of the six piers were reported by the NYSDOT Technical Services Division with the following conclusions:

1. Overall corrosion loss in the areas studied was minor.
2. Corrosion rates in industrial waste fills encountered did not differ from those in natural soils.
3. Corrosion rates in disturbed soils did not differ from those found in undisturbed soils.
4. Such soil parameters as resistivity, chlorides, and sulfates (used to select non-corrosive soils for use in mechanically stabilized reinforced earth walls) in this case were not good predictors of corrosion activity.
5. Electrical tests, in combination with each other or with soil parameters,were not good predictors of section loss.

6. As observed in previous H-pile corrosion studies, steel located below the water table did not show significant section loss due to corrosion.

7. In this instance, the three resistivity measurement methods generally agreed, but local field conditions affected the Geonor probe and Modified Wenner Method values.

The investigators recommended that all future NYSDOT studies should be restricted to steel H-piles in disturbed soils above the water table.

SOIL CORROSION TESTING

In 1982, following the experience with the Sweet Home Road Crossing, FHWA was contacted to obtain recommendations for electrochemical corrosion testing and the following suggestions were received (note that no test procedures were recommended):

CORROSION	
Resistivity	> 3,000 ohm-centimeters
pH	5-10
Chlorides	< 2,000 parts per million
Sulphates	< 1,000 parts per million
Sulphides	< 300 parts per million

Test procedure recommendations were pursued with FHWA in early 1983. The response did not directly answer the test procedure question, but rather concurred with the NYSDOT decision to progress projects using natural materials based on satisfactory past performance, and manmade materials based on past testing, composition, and performance.

In 1989, FHWA recommended CALDOT Test 643 (Laboratory Method of Determining Minimum Resistivity), CALDOT Test 417 (Method of Testing Soils and Water for Sulfate Content) and CALDOT Test 422 (Method of Testing Soils and Waters for Chloride Content). By a Soil Mechanics Bureau Directive in November 1989, these tests and the NYSDOT Test Method for the Determination of pH of Water or Soil by pH Meter were adopted.

In March 1989, the Soil Mechanics Bureau alerted all NYSDOT geotechnical engineers to crushed stone aggregate sources statewide that might contain iron sulfide minerals. If backfill was to be supplied from one of these sources, sulfide testing might be required.

In 1991, the AASHTO Subcommittee on Materials (12) adopted the following standard test procedures for electrochemical testing of soils:

1. T 288-91 I (Determining Minimum Laboratory Soil Resistivity)
2. T 289-91 I (Determining pH of Soil for Use in Corrosion Testing)
3. T 290-91 I (Determining Water Soluble Sulfate Ion Content in Soil)
4. T 291-91 I (Determining Water Soluble Chloride Ion Content in Soil)

NYSDOT adopted these AASHTO procedures by a Soil Mechanics Bureau Directive in December 1992.

NYSDOT SPECIFICATIONS TODAY

Our current specifications for mechanically stabilized earth structures place important controls on backfill materials supplied by contractors, addressing issues of supply, process, gradation, and corrosion potential. Together these controls

assure that corrosion potential is minimized. For clarity, the entire backfill requirements for mechanically stabilized earth structures are quoted as follows:

"**BACKFILL.** Only suitable material shall be acceptable for backfill. Any mineral (inorganic) soil, blasted or broken rock, or similar materials of natural origin, including mixtures thereof, are allowable suitable materials. The backfill material for any mechanically stabilized earth structure shall come from a single source unless prior approval for use of designated multiple sources is obtained from the Director, Soil Mechanics Bureau.

Tests, Control and Acceptance Methods. Material tests and control methods pertaining to the backfill requirements will be performed in conformance with the procedures contained in the appropriate Departmental publications in effect on the date of the advertisement for bids. These publications are available upon request to the Regional Director, or the Director, Soil Mechanics Bureau. Acceptance of the backfill will be made in accordance with the procedural directives of the Soil Mechanics Bureau.

Backfill Material. The backfill material shall be stockpiled in accordance with S.C.P.-8, Procedures for the Control of Granular Materials, and shall be graded in accordance with TABLE 554.1.

TABLE 554-1

Sieve Size Designation	Percentage Passing by Weight
4 inch	100
1/4 inch square	30-100
No. 40 Mesh	0-60
No. 200 Mesh	0-15

Plasticity Index. If the State elects to test for plasticity, the Plasticity Index shall not exceed 5.

Durability. If the State elects to test for durability, material having a Magnesium Sulphate Soundness loss in excess of 30 percent will be rejected and will not be placed in the work.

Corrosion Potential. The State will test for corrosion potential. All stockpiled backfill materials will be tested for resistivity and pH, and may be tested for sulphides at the Department's discretion. Material failing to meet the specification requirements of Table 554-2, for those tests which are performed, will be rejected except as specified below:

Material failing to meet the resistivity criterion may be tested for sulphate and chlorides. Material meeting the criteria for both sulphates and chlorides and having a minimum resistivity greater than 1,000 ohm-cm will be acceptable."

TABLE 554-2

Resistivity	not less than 3,000 ohm-cm
pH	5 to 10
Sulphates	not to exceed 200 mg/kg
Sulphides	not to exceed 300 mg/kg
Chlorides	not to exceed 100 mg/kg

In addition to these specification requirements, the Soil Mechanics Bureau requires soil samples for construction monitoring on all projects. When one or more stockpiles are approved for backfill, the number of monitoring samples is determined. The number is based on laboratory test result history of the granular material source and volume of material required for construction of the mechanically stabilized earth

structure. The minimum number is one and the maximum number varies. These informational monitoring samples are tested, but results are not used for acceptance/rejection of the backfill material; acceptance is granted when the stockpile is approved.

STEEL H-PILES

Foundation designs involving installation of steel H-piles require an adequate subsurface exploration program to determine if manmade fill materials are present. Where deemed necessary, soil samples are tested in the laboratory for corrosion potential. Some foundation designs in recent years have been modified because of concerns about high corrosion potential. In some instances, this has required removal and replacement of manmade materials with natural granular material, and in others, pile type has been changed. Another alternative sometimes considered is coating of steel H-piles.

CURRENT PERSPECTIVES

NYSDOT's experience with corrosion since 1988, combined with communication received concerning similar experiences in another state, leads to the following observations:

1. Geotechnical engineering solutions to soil and foundation problems are requiring increased use of steel elements in the soil environment.
2. The quantity of use of steel elements for piles, sheet piles, soil reinforcing materials, soil nails, rock bolts, tiebacks and permanent anchors demands greater knowledge of field performance for proper evaluation of assumptions concerning design life.
3. NYSDOT has no soil corrosion experts on staff to evaluate field and lab test

results for design, offer sound direction to improve standards, or evaluate performance of completed structures.

4. Civil engineering curricula, particularly geotechnical engineering courses should address the corrosion issue.
5. Research must increase in this critical area.
6. The geotechnical engineering community must share case history experience.
7. Bridge design engineers must be more sensitive to corrosion concerns affecting their pile designs and of measures that can be taken to avoid or counteract potential problems.
8. Electrochemical lab test results must be correlated to field performance. If necessary, lab tests should be improved.
9. Agencies should maintain a current inventory of all installed steel elements in the soil and rock environments, including: 1) mechanically stabilized earth structures, 2) soil nails, 3) permanent ground anchors, 4) rock bolts, 5) steel piles, and 6) permanent sheet piles.
10. Investigations to date indicate that corrosion is most severe in manmade fills with high groundwater levels.

THE FUTURE

Geotechnical engineering techniques will continue to require installation of steel elements in the soil environment. If predictive capabilities of soil corrosion rates are to improve, Engineers must be proactive to assure positive results:

1. Formal research is needed to augment practical performance evaluations.
2. Practicing engineers must maintain communication with other federal, state, consultant and academic professionals involved in corrosion research.
3. Case histories of corrosion problems must be written and widely distributed

for the benefit of the engineering community.

4. Geotechnical and bridge design engineers should remain alert to new opportunities for performance evaluation.

5. Existing structures built before proven investigative and laboratory testing capabilities were available should be evaluated for actual state of corrosion to provide realistic estimates of remaining structural life.

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